Intelligent Control of a Laboratory Industrial System (FESTO MPS PA)

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Abstract: The paper investigates the application of genetic algorithms, fuzzy logic, and fuzzy sliding mode to improve control in complex systems, with a specific focus on the FESTO controlled system. Genetic algorithms are utilized to determine the controller parameters, while fuzzy logic and fuzzy sliding mode are employed to handle uncertainty and dynamically adapt control settings. The study delves into the theoretical foundations of these methodologies, outlines the research methodology, and scrutinizes the results. The findings underscore that incorporating these techniques enhances the adaptability and efficiency of the FESTO control system in intricate and uncertain environments. This research lays the groundwork for innovative strategies aimed at enhancing control in complex systems..
Keywords: Genetic Algorithms, Fuzzy Logic, Fuzzy Sliding Mode.

I. INTRODUCTION

Control in complex systems presents formidable challenges due to uncertainties and dynamic environments. Traditional methods often struggle to adapt, prompting exploration of alternative approaches. Genetic algorithms (GAs), inspired by natural selection, efficiently optimize control parameters, enhancing system performance and robustness.

Fuzzy logic handles uncertainty by representing imprecise information with degrees of truth. Its flexible decision-making improves control system adaptability to uncertain environments, fostering stability and performance.

Fuzzy sliding mode control combines robust sliding mode control with fuzzy logic, offering smooth mode switching for improved transient response and reduced chattering. Applied to the Festo system, known for complexity and variability, these techniques promise enhanced control performance in real-world applications.

This paper examines the theoretical underpinnings of Gas, fuzzy logic, and fuzzy sliding mode control, their integration into control systems, and reviews state-of-the-art research. By synthesizing literature and empirical evidence, this research advances understanding of control methodologies for complex systems, paving the way for future innovations.

II. Description of FESTO MPS PA CompactWorkstation :

The FESTO MPS PA Compact Workstation is a laboratory platform used to designvarious types of PID controllers. Theworkstation consists of pipes, two tanks, different types of sensors, actuators, and a PLC S7-300 controller, allowing the testing of various control systems.[18].

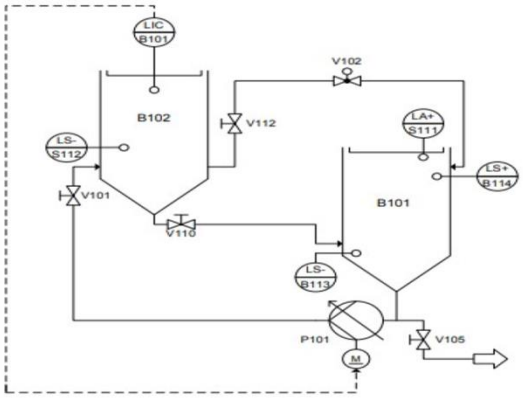

Figure 1: Presentation of Festo MPS PA workstation

III. Genetic algorithm (GA):

A genetic algorithm (GA) is a computational optimization technique inspired by the principles of natural selection and genetics. It

uses a population-based search strategy to iteratively evolve potential solutions to a problem by mimicking genetic operations such asselection, crossover (recombination), and mutation. Gas are particularly effective for solving complex optimization problems with large search spaces, non-linearities, and multiple objectives. They are widely applied in various fields including engineering, economics, biology, and machine learning tofind near-optimal solutions in acomputationally efficient manner.[1-6][8][9]

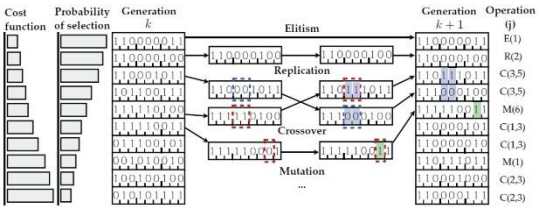

Figure 2 .Illustration of an evolution in genetic algorithms.

1. **Optimization of a PI controller using genetic algorithm:**

In this experiment, we will use the genetic algorithm to adjust a proportional-integral (PI) controller. The PI control is one of the simplest and most widely used control architectures in industrial control systems, particularly for position and speed control of motors, for adjusting various subsystems in an automobile, and for controlling pressure and temperature in modern espresso machines. A schematic of the PI control is shown in Figure3.

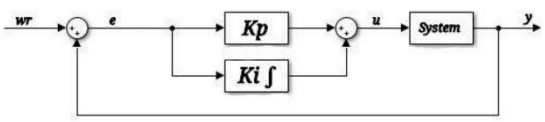

Figure 3. A schematic of PI controller.

In this example, we explore the use of a genetic algorithm to find effective PI gains to minimize a cost function. We utilize an LQR cost function:

$$J = [Q(wr - y)^2 + Ru^2]\, d\tau \quad (1)$$

With Q = 1 andR = 0.001 for. The cost function aims to minimize the error between the setpoint and the system response.[7].

2. **Simulation and results:**

We have selected the parameters (presented in Table 1) to run our Matlab simulation on the controlled system.

Table 1.parameters for GA

Population size	100
Genetarions size	15
Mutation	0.2
Croissement	One point 70 %
Replication	20 %
Selection	10 %

After running the code on MATLAB, we obtain :

1- kp and ki valeus:

Kp=26,1235 ki=8,0405

2- Cost function which is : 0,3992

The evolution of the cost function across different generations is depicted in Figure 4. As the generations progress, thecost function steadily decreases. As the genetic algorithm progresses, the PI gains begin to cluster around the optimal solution.

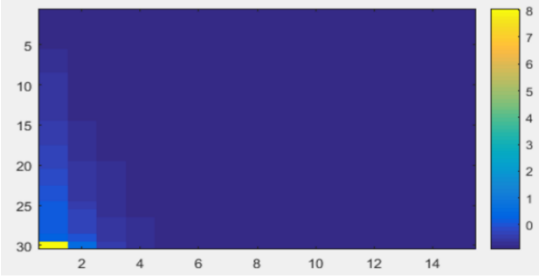

Figure 4.Cost function across generations.

The evolution of the step response of thesystem across different generations is presented in Figures 5, 6 and 7.

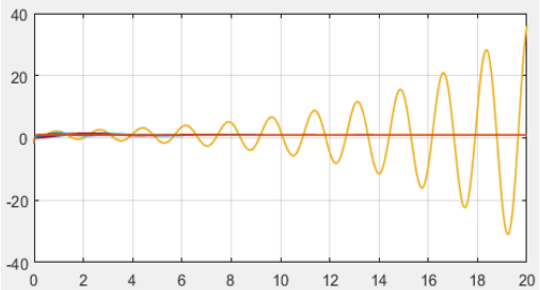

Figure 5 . Step response output for 1 st generation.

Figure 5 displays the step response output of the PI controllers from the first generation. It is evident from this graph that many controllers fail to stabilize the system, resulting in large deviations in response .

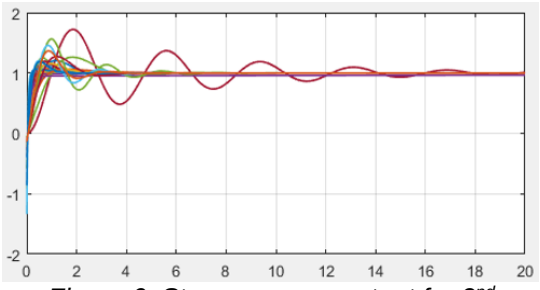

Figure 6. Step response output for 2nd generation.

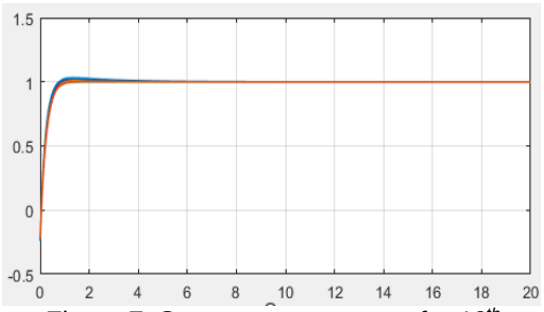

Figure 7. Step response output for 10th generation

Figure 6 illustrates the step response output of the PI controllers from the 2nd generation. Figure 7 depicts the output of the 10th generation. Overall, these controllers are more effective in producing a stable step response. The improvement in the system's step response towards stability across generations and the increase in system speed are notable.

IV. Fuzzy logic controller (FL):

Fuzzy logic is a computational methodology that deals with uncertainty by allowing for gradual transitions between true and false states, using a continuum of truth values between 0 and 1. It employs linguistic variables, fuzzy sets, and membership functions to model imprecise or vague information, capturing qualitative knowledge effectively. Fuzzy logic systems utilize fuzzy inference mechanisms, such as fuzzy rules and operations, to derive decisions from fuzzy inputs, enhancing adaptability and robustness in complex systems. [9][10][11][12].

1- tuning PI parameters using fuzzy logic

In our study, we chose to use a Mamdani-type fuzzy inference system (FIS), although it is possible to use a Sugeno-type system.

A- Fuzzification: here we define input and output variables .[16][23]

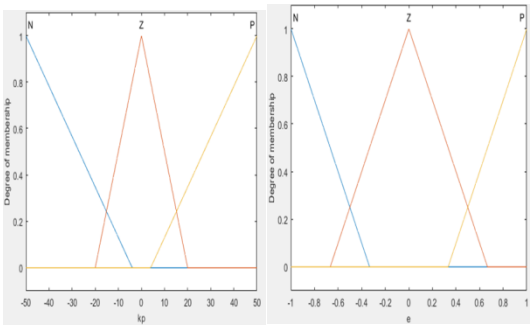

Figure 8. Fuzzification of input and output variables

B- Rule base

Ec / E	N	Z	P
N	N	N	N
Z	N	P	P
P	P	P	P

Table 2. Fuzzy rules for tuning Kp.

Ec / e	N	Z	P
N	Z	Z	Z
Z	P	P	P
P	Z	Z	Z

Table 3. Fuzzy rules for tuning Ki.[19].

C- Diffuzification :

In this step we optimize the values of KP and Ki.

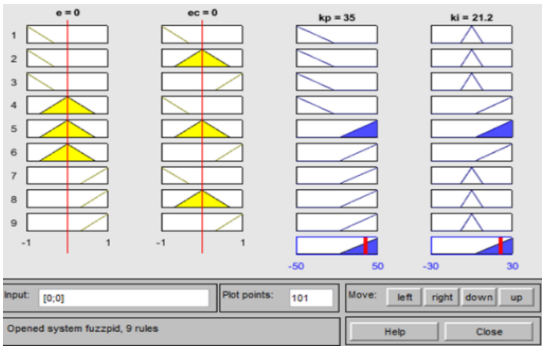

Figure 9.Optimization of the values of Kp and Ki.

2- Simulation and results

Testing the fuzzy inference system(FIS) can be achieved using the `evalfis` command. If the matrix representing the FIS is not present in the workspace, it can be read using the `readfis` command .After execution, the following results are obtained:

- The input signal is depicted in Figure (10), showing variation towards a

constant value, which ensures system stability at a constant value.

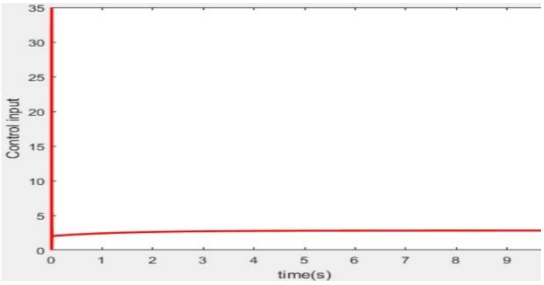

Figure 10. The input signal

- The step response of the controlled system is presented in Figure IV.16. It converges towards an ideal value within 5 seconds without oscillations. The system's speed is notable, with the absence of oscillations and overshoot.

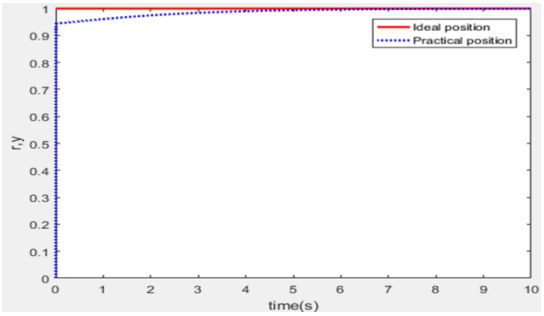

Figure 11. The step response of system

V. Sliding and Fuzzy Sliding Mode:

Sliding mode control is a robust control technique that aims to drive a system's state trajectory into a predefined sliding surface and maintain it there regardless of uncertainties or disturbances. It involves designing a control law such that the system's dynamics force the state trajectories onto this sliding surface, ensuring stability and robustness. On the other hand, fuzzy sliding mode control combines the robustness of sliding mode control with the adaptability and flexibility of fuzzy logic systems. It integrates fuzzy logic-based adaptive mechanisms into the sliding mode framework, allowing for improved performance in the presence of uncertainties and non-linearities while reducing chattering effects often associated with traditional sliding mode control.[14][17][18][23][25-27].

1- Design slidingsurface:

Wedefine the system controlled in statspace as below:

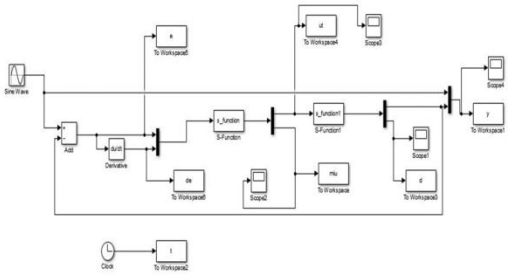

Figure 12 . State space of system controlled.

Let's consider the disturbance D(t) in the form of the following Gaussian function:

$$D(t) = 5exp\left(-\frac{(t-c_i)^2}{2{b_i}^2}\right)$$

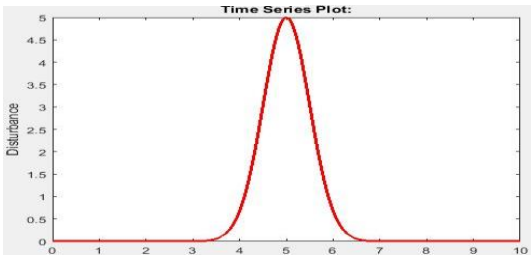

Figure 12. Distrubance D(t)

2- The fuzzysystem:

The fuzzy system is established within the function_s, and the rule library is kept running using persistent control. The membership functions for the inputs and outputs of the fuzzy system are presented in Figure 13.

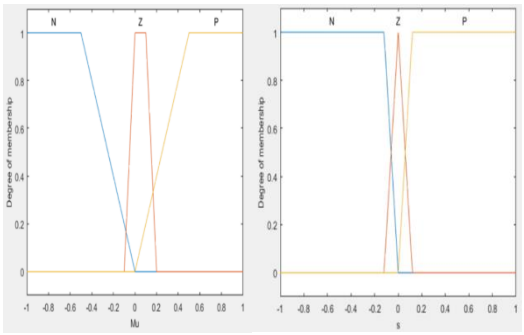

Figure 13. The membership functions of inputs and ouput.

- **The traditional sliding mode**

For μ = 1 ,

We provide the system with a sinusoidal input and execute the program.

✓ We obtain a highly sinusoidal output that rapidly and continuously approaches the

ideal signal in a stable manner despite the mentioned disturbance.

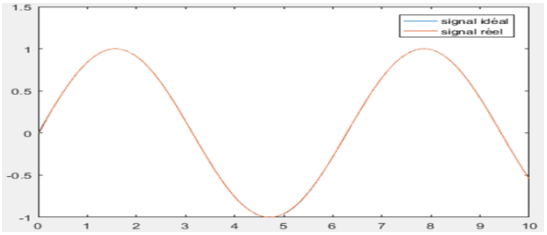

Figure 14. Response signal .

With a control command u(t) depicted in Figure 15, stability of the system is implied, but the phenomenon of chattering is observed.

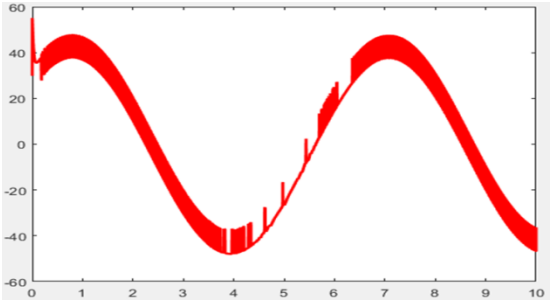

Figure 15. Command signal u(t).

- **The fuzzy sliding mode**

For μ ≠ 1 ,

We obtain:

✓ An output very close to the ideal response with remarkable speed.

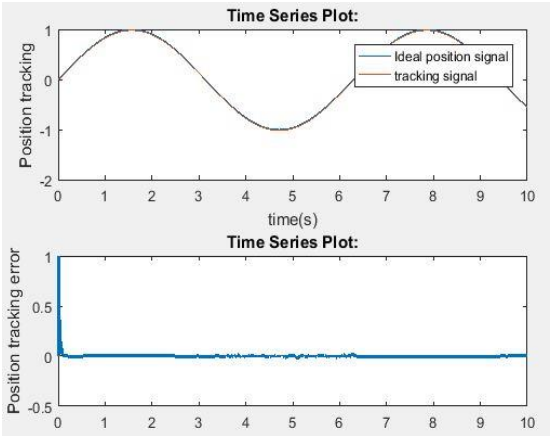

Figure 16. The step response for system controlled.

✓ A control commandu(t) that ensures stability and effectiveness of the system with the absence of oscillations present in the classic sliding mode. Our control mode eliminates chattering. The command is depicted in Figure 17.

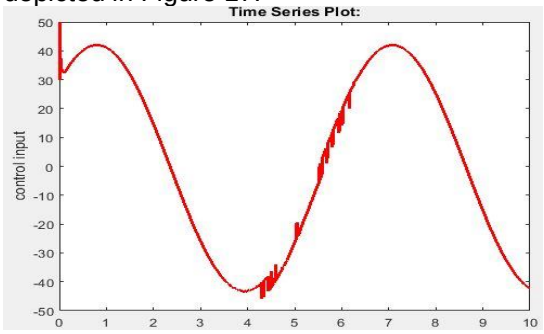

Figure 17. Control command of system controlled by FSMC.

The variation of the coefficient *u*deduced by fuzzy logic is presented in Figure 18. The coefficient tends towards -1 in the case of disturbance. This means that the contribution of the switching command has become very significant compared to the equivalent command.[24]

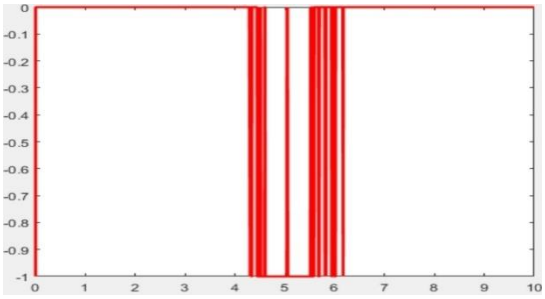

Figure 18. Variation of coefficient u.

Conclusion :

In conclusion, we have explored the application of genetic optimization, fuzzy, and sliding techniques to the FESTO controlled system. Genetic optimization has allowed for the optimization of PI controller parameters, thereby providing an accurate and stable system response.

The application of fuzzy logic has enabled control adaptation based on changing system conditions, using fuzzy sets and linguistic rules for decision-making. Finally, the application of sliding mode control has enhanced the stability and disturbance resistance of the FESTO PI controller.

These combined applications of genetic optimization, fuzzy, and sliding techniques have improved the control performance of FESTO, offering an adaptive and precise response for our system.[15][16][23].

Abbreviations and Acronyms

- GA: Genetic Algorithms
- FL: Fuzzy Logic
- SMC: Sliding Mode Control
- FSMC: Fuzzy Sliding Mode Control

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